

Quality of Irrigation Water

The concentration and composition of dissolved constituents in a water determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Much work has been done on quality of irrigation water. The United States Geological Survey is very active in general quality-of-water studies, and the analyses made by this agency are published at irregular intervals in the USGS Water-Supply Papers. In addition to current programs, analyses dating back to the beginning of irrigation in the western United States are recorded in this series. The Geological Survey took the leadership in preparing an index of water analyses that has proved to be very useful.¹³ Agricultural experiment stations in the Western States have also been active in quality-of-water studies and have published a number of bulletins on this subject (Smith, 1949; Smith and others, 1949; Miller, 1950; Jensen and others, 1951; Thorne and Thorne, 1951).

The Rubidoux Laboratory since 1928 has analyzed more than 22,000 samples of irrigation water. Much of the information has been published, and all of it is available in the records of the Laboratory. This work shows that poor quality of both surface and ground waters is a limiting factor in the irrigation of many areas in this country and abroad.

There are many places in western United States, particularly in the desert areas of California, Arizona, Texas, and New Mexico, and also in the other parts of the world, where ground water is available but the quality is questionable or unsatisfactory. Similarly, where surface waters are used, the present rate of increase of irrigation development and changes in management practices are resulting in serious quality-of-water problems. There is the tendency to divert for irrigation all of the available water. This means that over a period of years the downstream diversions may change from uncontaminated river water to a substantial proportion of drainage return-flow of poor quality. To cope with such problems, it is necessary to have detailed information concerning the quality of irrigation water and a background of experience relating to the effect of irrigation waters on soils and crops.

¹³ U. S. DEPARTMENT OF THE INTERIOR, GEOLOGICAL SURVEY. INVENTORY OF PUBLISHED AND UNPUBLISHED CHEMICAL ANALYSES OF SURFACE WATERS IN THE WESTERN UNITED STATES, NOTES ON HYDROLOGIC ACTIVITIES. Bul. No. 2, October 1948. [Processed.]

Methods of Analysis

The methods used by this Laboratory for the analysis of irrigation waters are given in chapter 8, Methods 70 to 86. The Versenate titration (Method 79) for calcium plus magnesium, the flame photometer method for sodium and potassium (Methods 80b and 81c), and the colorimetric method for boron (Method 73b), make possible rapid determinations without sacrificing accuracy. Also, the volume of water required for an analysis is less, thus simplifying the collection and transportation of samples.

If all of the principal constituents have been determined and expressed in chemical equivalents, the sum of the cations should equal the sum of the anions, and a lack of balance indicates an error. There are a number of ways in which a water analysis can be checked. The numerical value of the ratio—electrical conductivity in micromhos per centimeter divided by cations in milliequivalents per liter—should be about 100 for most waters (fig. 20). This ratio may be as low as 80 for bicarbonate or sulfate waters in which calcium and magnesium are high, but for chloride waters that are high in sodium the ratio may be as high as 110. The numerical value of the ratio—dissolved solids in parts per million divided by conductivity in micromhos per centimeter—should be approximately 0.64 (fig. 21). A third ratio—dissolved solids in parts per million divided by cations in milliequivalents per liter—has a value of approximately 64. These values are averages based on a large number of determinations for natural waters.

Characteristics That Determine Quality

The characteristics of an irrigation water that appear to be most important in determining its quality are: (1) Total concentration of soluble salts; (2) relative proportion of sodium to other cations; (3) concentration of boron or other elements that may be toxic; and (4) under some conditions, the bicarbonate concentration as related to the concentration of calcium plus magnesium.

Electrical Conductivity

The total concentration of soluble salts in irrigation waters can be adequately expressed for purposes of diagnosis and classification in terms of electrical con-

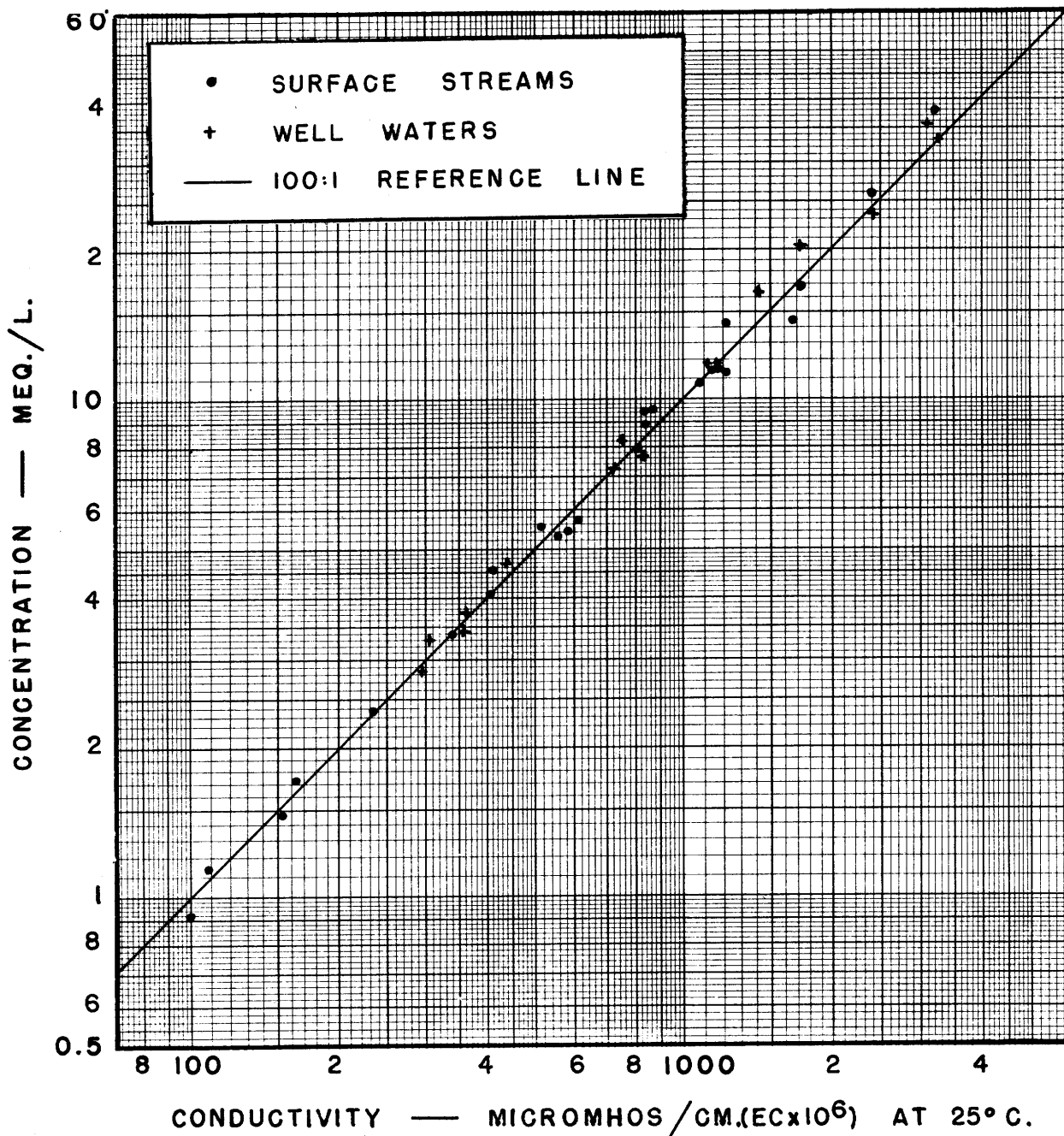


FIGURE 20.—Concentration of irrigation waters in milliequivalents per liter of cations as related to conductivity.

ductivity. The conductivity is useful because it can be readily and precisely determined.

Nearly all irrigation waters that have been used successfully for a considerable time have conductivity values less than 2,250 micromhos/cm. Waters of higher conductivity are used occasionally, but crop production, except in unusual situations, has not been satisfactory.

Saline soils are those in which the conductivity of

the saturation extract is greater than 4 millimhos/cm., or 4,000 micromhos/cm. It has been found that the conductivity of the saturation extract of a soil, in the absence of salt accumulation from ground water, usually ranges from 2 to 10 times as high as the conductivity of the applied irrigation water. This increase in the salt concentration is the result of continual moisture extraction by plant roots and evaporation. Therefore, the use of waters of moderate to high salt content may

result in saline conditions, even where drainage is satisfactory. In general, waters with conductivity values below 750 micromhos/cm. are satisfactory for irrigation insofar as salt content is concerned, although salt-sensitive crops may be adversely affected by the use of irrigation waters having conductivity values in the range 250 to 750 micromhos/cm.

Waters in the range of 750 to 2,250 micromhos/cm. are widely used, and satisfactory crop growth is obtained under good management and favorable drainage conditions, but saline conditions will develop if leaching

and drainage are inadequate. Use of waters with conductivity values above 2,250 micromhos/cm. is the exception, and very few instances can be cited where such waters have been used successfully. Only the more salt-tolerant crops can be grown with such waters and then only when the water is used copiously and the subsoil drainage is good.

As discussed in chapter 3, the steady-state leaching requirement for soils where no precipitation of salts occurs is directly related to the electrical conductivity of the irrigation water and the permissible conductivity

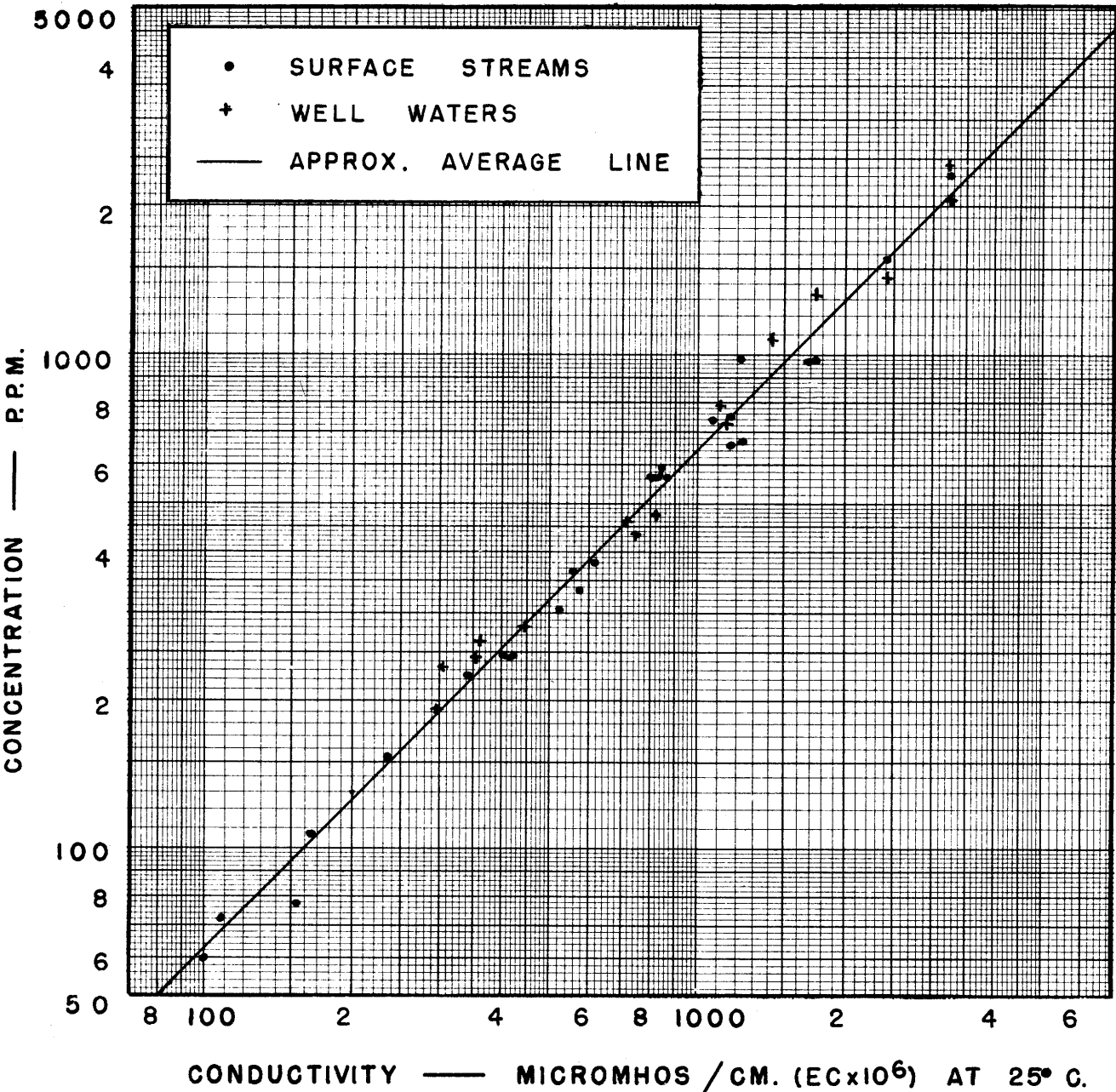


FIGURE 21.—Concentration of irrigation waters in parts per million as related to conductivity.

of the water draining from the root zone. The leaching requirements for specified electrical conductivity values of the irrigation and drainage waters, as determined from equation 2, chapter 3, are given in table 10.

TABLE 10.—*Leaching requirement¹ as related to the electrical conductivities of the irrigation and drainage waters*

Electrical conductivity of irrigation waters (micromhos/cm.)	Leaching requirement for the indicated maximum values of the conductivity of the drainage water at the bottom of the root zone			
	4 mmhos/cm.	8 mmhos/cm.	12 mmhos/cm.	16 mmhos/cm.
	Percent	Percent	Percent	Percent
100	2.5	1.2	0.8	0.6
250	6.2	3.1	2.1	1.6
750	18.8	9.4	6.2	4.7
2,250	56.2	28.1	18.8	14.1
5,000		62.5	41.7	31.2

¹ Fraction of the applied irrigation water that must be leached through the root zone expressed as percent.

Although, for reasons stated in chapter 3, these leaching requirement values are probably somewhat high, they illustrate the manner in which the electrical conductivity of irrigation waters influences the leaching requirement under various levels of soil salinity, expressed in terms of electrical conductivity of the soil solution at the bottom of the root zone. It is apparent that the water-transmission and drainage properties of the soil and the salt tolerance of the crop to be grown are important factors in appraising irrigation waters from the standpoint of total salt concentration.

Sodium-Adsorption-Ratio

The soluble inorganic constituents of irrigation waters react with soils as ions rather than as molecules. The principal cations are calcium, magnesium, and sodium, with small quantities of potassium ordinarily present. The principal anions are carbonate, bicarbonate, sulfate, and chloride, with fluoride and nitrate occurring in low concentrations. The alkali hazard involved in the use of a water for irrigation is determined by the absolute and relative concentrations of the cations. If the proportion of sodium is high, the alkali hazard is high; and, conversely, if calcium and magnesium predominate, the hazard is low. The importance of the cationic constituents of an irrigation water in relation to the chemical and physical properties of the soil was recognized even before cation exchange reactions were widely understood. Scofield and Headley (1921) summarized the results of a series of alkali reclamation experiments with the statement: "Hard water makes soft land and soft water makes hard land." Alkali soils are formed by accumulation of exchangeable sodium and are often characterized by poor tilth and low permeability.

In the past the relative proportion of sodium to other cations in an irrigation water usually has been expressed in terms of the soluble-sodium percentage. However, as was shown in chapter 2, the sodium-adsorption-ratio of a soil solution is simply related to the adsorption of sodium by the soil; consequently, this ratio has certain advantages for use as an index of the sodium or alkali hazard of the water. This ratio is defined by the equation:

$$SAR = Na^+ / \sqrt{(Ca^{++} + Mg^{++}) / 2}$$

where Na^+ , Ca^{++} , and Mg^{++} represent the concentrations in milliequivalents per liter of the respective ions. A nomogram for estimating the *SAR* value of an irrigation water is shown in figure 22. This nomogram is similar to figure 27, but figure 22 has scales more suitable for the cationic concentrations encountered in irrigation waters.

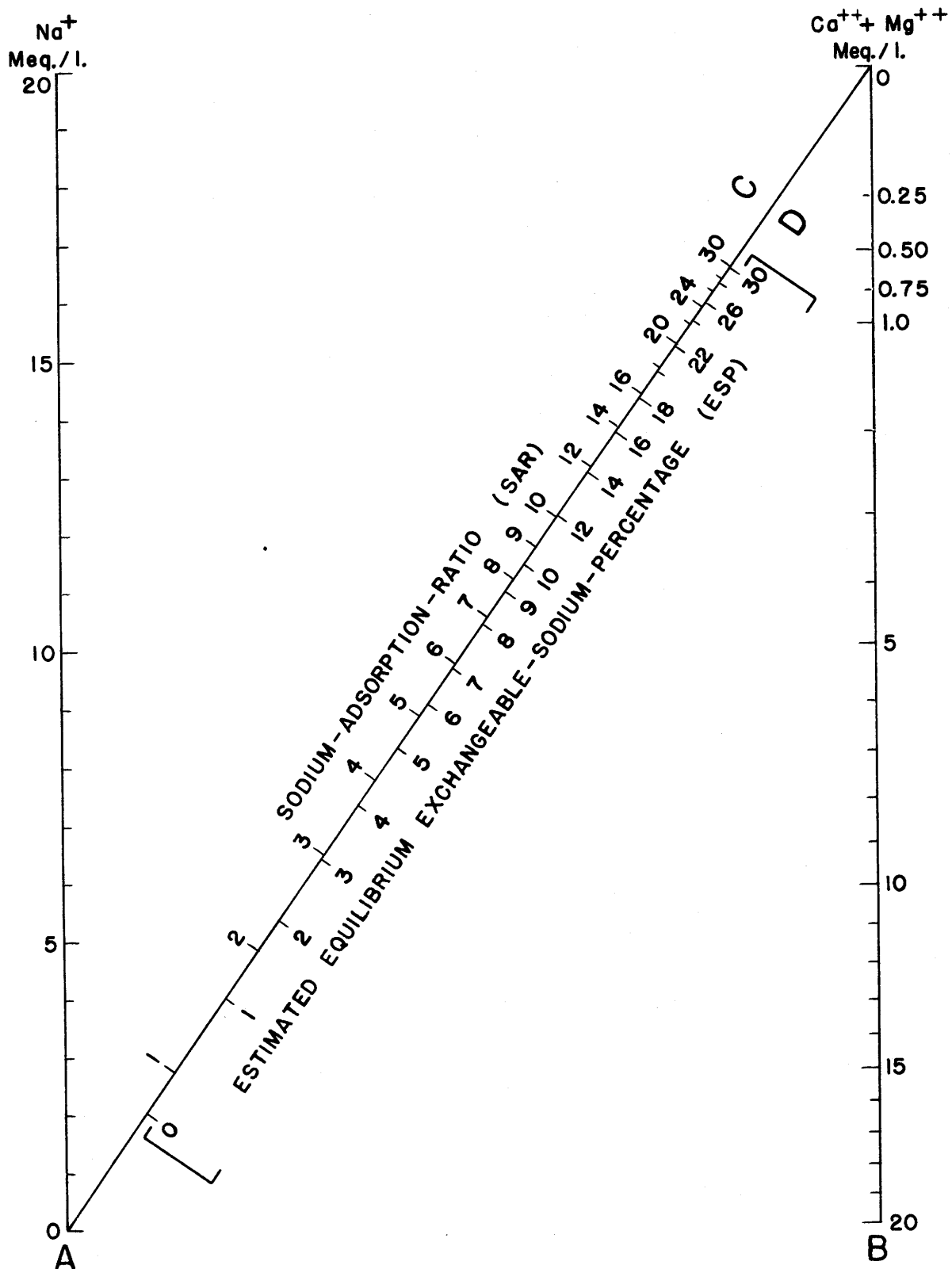
An *ESP* scale is included in the nomogram opposite the *SAR* scale. This *ESP* scale is based on the regression line shown in figure 9, chapter 2, in which the relation between *SAR* and *ESP* was given as

$$ESP = \frac{100 (-.0126 + .01475 SAR)}{1 + (-.0126 + .01475 SAR)}$$

This empirical equation was used to relate the *ESP* scale to the *SAR* scale in figure 22. After the *SAR* value of an irrigation water is determined by use of the nomogram, it is possible from the central scale to estimate the *ESP* value of a soil that is at equilibrium with the irrigation water. It is to be expected, however, that this condition would not often occur in the field, because the soil solution is nearly always appreciably more concentrated than the irrigation water.

The concentration of the soil solution is increased by the extraction of water from the soil by roots and by evaporation. As the quantity of salt absorbed by plants is relatively small, the solution remaining in the soil is more concentrated than the applied irrigation water. At the next irrigation this more concentrated solution may be displaced downward or diluted, and so the concentration of the solution in contact with the soil varies with time and location in the profile. It is not unusual to find shallow ground water or drainage water that is from 2 to 10 times as concentrated as the irrigation water. It is reasonable to assume, however, that for a limited depth of soil, such as the top 12 inches, the concentration of the soil solution is not, on the average, more than 2 or 3 times the concentration of the irrigation water.

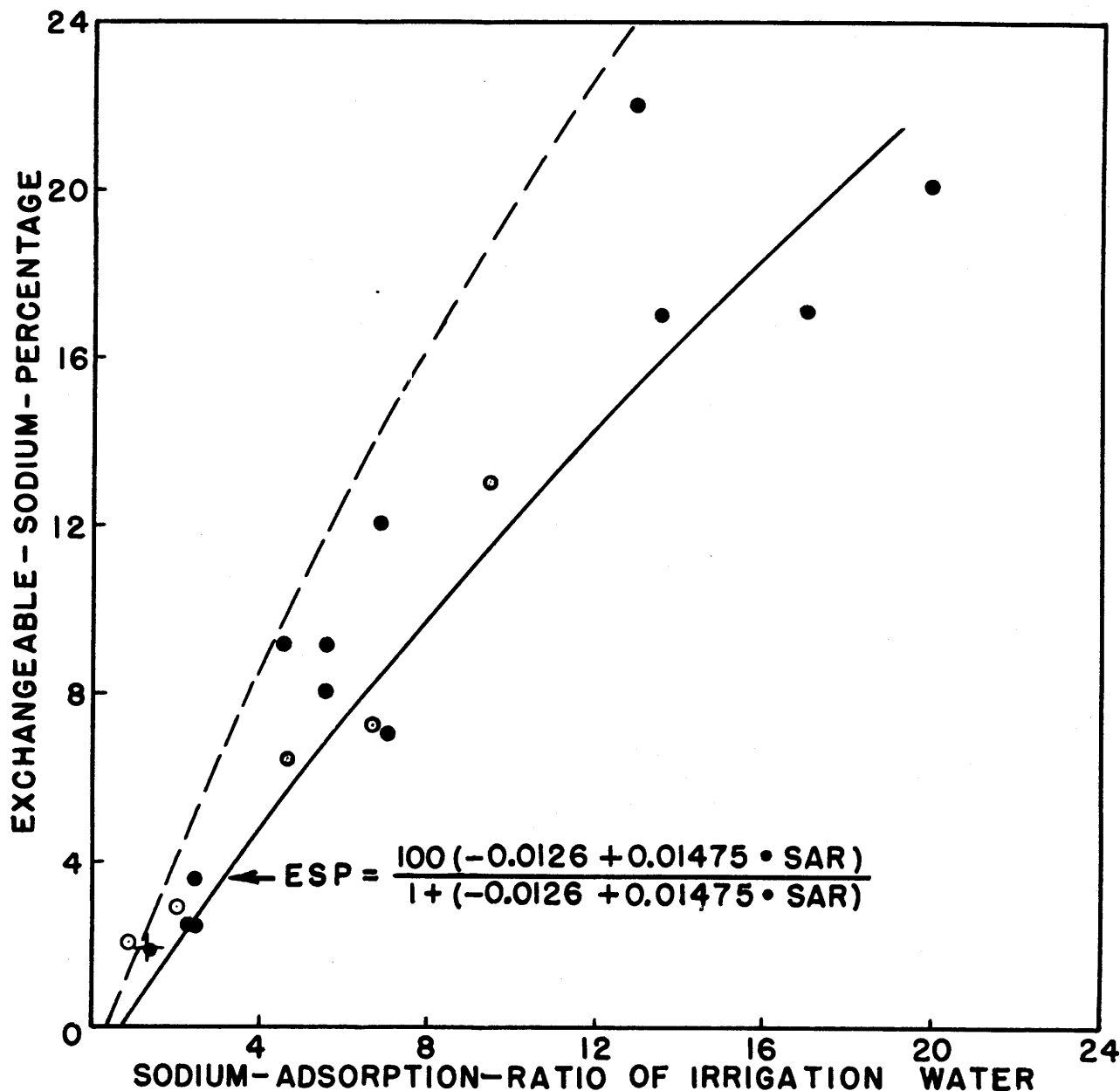
Under conditions in soil where it is permissible to neglect precipitation and absorption of soluble salts by roots, it is clear that irrigation water, after entering the soil, becomes more concentrated without change in relative composition, i. e., the soluble-sodium percentage does not change. The *SAR* value, however, increases in proportion to the square root of the total concentration, i. e., if the concentration is doubled the *SAR* value increases by a factor of 1.41. If the concentration is quadrupled the *SAR* value will be doubled.



It has been observed that where an irrigation water of relatively constant composition is used and drainage conditions are good, the *ESP* value of soil varies only slightly from season to season or from year to year. This implies that the cation-exchange material of the soil has reached a steady state relative to the cations in the soil solution which are derived from the irrigation water. All suitable data bearing on the relationship between the soluble cations of the irrigation water and the exchangeable cations of the soil have been assembled from the records of the Laboratory. Only

those instances were selected in which the drainage was known to be good and only the surface sample of soil from each site was considered. It was further required that the composition of the irrigation water be relatively invariant with time and that the water must have been used for many seasons in the field experiments or for many irrigations in experiments conducted at the Laboratory.

The relation between the *SAR* value of the irrigation waters and the *ESP* values of the soil samples is shown by the points on the graph in figure 23. The solid



curve represents the relation between *SAR* and *ESP* given by the equation shown in the figure, and also indicated by scales C and D in the nomogram of figure 22. It is apparent that, under the conditions existing in the field, the *ESP* values of the soil samples are generally higher than the estimated values. The deviations from the solid curve are undoubtedly owing to the fact that the concentrations of the soil solutions are somewhat higher than the concentrations of the irrigation waters.

The dotted curve in figure 23 shows the *ESP* values that would be attained by the soils, assuming a three-fold increase in the concentration of the irrigation waters. In other words, if the soluble-sodium percentages of the irrigation waters after entering the soils remain unchanged but the total concentrations increase by a factor of 3, the *SAR* values would increase by a factor equal to the square root of 3 and the resulting predicted *ESP* values for the samples would lie along the dotted curve in the figure. The distribution of the points on the graph that represent the field samples indicates that the saturation extracts were 1 to 3 times as concentrated as the irrigation waters applied.

More data are needed to explain the relation of exchangeable sodium to water quality and irrigation practices. On the basis of the relationship shown in figure 23, *SAR* appears to be a useful index for designating the sodium hazard of waters used for irrigation.

Boron

Boron is a constituent of practically all natural waters, the concentration varying from traces to several parts per million. It is essential to plant growth, but is exceedingly toxic at concentrations only slightly above optimum. Eaton (1944) found that many plants made normal growth in sand cultures with a trace of boron (0.03 to 0.04 p. p. m.), and that injury often occurred in cultures containing 1 p. p. m.

Bicarbonate

In waters containing high concentrations of bicarbonate ion, there is a tendency for calcium and magnesium to precipitate as carbonates as the soil solution becomes more concentrated. This reaction does not go to completion under ordinary circumstances, but insofar as it does proceed, the concentrations of calcium and magnesium are reduced and the relative proportion of sodium is increased. Eaton (1950) uses three terms in connection with this reaction:

(1) Soluble-sodium percentage "found" = $(\text{Na}^+ \times 100) / (\text{Ca}^{++} + \text{Mg}^{++} + \text{Na}^+)$; (2) Soluble-sodium percentage "possible" = $(\text{Na}^+ \times 100) / ((\text{Ca}^{++} + \text{Mg}^{++} + \text{Na}^+) - (\text{CO}_3^{--} + \text{HCO}_3^-))$, where the $\text{CO}_3^{--} + \text{HCO}_3^-$ deduction does not exceed $\text{Ca}^{++} + \text{Mg}^{++}$; (3) "Residual Na_2CO_3 " = $(\text{CO}_3^{--} + \text{HCO}_3^-) - (\text{Ca}^{++} + \text{Mg}^{++})$.

In these relations the ionic constituents are expressed as milliequivalents per liter.

The influence of the bicarbonate ion concentration of irrigation waters upon the exchangeable-sodium-percentage has been studied at the Laboratory. One

experiment involved the growth of Rhodes grass in pots of Hanford loam soil. The soils were irrigated with the waters under test, then allowed to dry to a soil-moisture tension of about 700 to 800 cm. of water between irrigations. There were low- and high-leaching treatments. The high-leaching treatment provided for the application of excess irrigation water so that about 25 percent of the applied irrigation water was collected as percolate after each irrigation. The low-leaching regime provided for the same proportion of leachate every fourth irrigation. Exchangeable-sodium-percentages were somewhat greater with the low-leaching treatments than with the high. Table 11 describes the irrigation waters that were tested and reports the results of the analyses of soil samples from the low-leaching treatments. The soil samples were collected after the 42d and 86th irrigations.

The use of two of the bicarbonate waters, 20b and 10b, gave rise to substantially higher *ESP* values than the corresponding chloride waters, 20a and 10a (table 11). At the end of 42 irrigations, there was no appreciable difference between the 5a and 5b waters, but a significant difference was found after the 86th irrigation. With the remaining waters, there appears to be no difference between the chloride and bicarbonate treatments.

Typical Waters

The analyses of a group of surface waters from western United States that are typical of the waters that are being used for irrigation purposes are presented in table 12. The composition of a surface water may vary considerably, but the analyses shown were selected to represent average conditions.

Ground waters are much more variable in composition than surface waters. With few exceptions, it is not possible to select ground waters that are typical of an area or to generalize about the ground waters of a given basin. Analyses of samples from a large number of wells in the Coachella Valley in Riverside County, California, illustrate this point. Electrical conductivity varies from 208 to 13,200 micromhos/cm; boron from a trace to 3.15 p. p. m., and soluble-sodium percentage (SSP) from 21 to 97. Even where wells are only a short distance apart or are pumping from different strata, great variation is sometimes noted. Two wells within a half mile of each other had conductivities of 13,200 and 604 micromhos/cm., and 3.03 and 0.38 p. p. m. boron, respectively. The first of these wells is 565 feet deep and the second 180 feet deep. The quality of the water from different strata tapped by the same well may vary, or the quality may change with length of time of pumping. This change with time is usually associated with overpumping but it does not often occur. The quality of water from a new well should be determined prior to its use for irrigation.

Classification of Irrigation Waters

In classification of irrigation waters, it is assumed that the water will be used under average conditions

TABLE 11.—*The composition of the irrigation waters used and the analyses of soil samples from a bicarbonate experiment at the Laboratory; low-leaching noncalcareous treatments*

Irrigation water							Analyses of soil samples collected after—							
Irrig. water No.	Concentration	Composition				Residual Na ₂ CO ₃	Irrigation No. 42				Irrigation No. 86			
		Ca ⁺⁺	Na ⁺	HCO ₃ ⁻	Cl ⁻		EC _e × 10 ³ at 25° C.	pH _e	ES	ESP	EC _e × 10 ³ at 25° C.	pH _e	ES	ESP
		Meq./l.	Percent	Percent	Percent				Meq./100 gm.				Meq./100 gm.	
20a ..	20.0	25	75	0	100	0	3.73	6.8	1.16	12	5.30	6.8	1.40	16
20b ..	20.0	25	75	50	50	5.0	5.94	8.6	4.52	52	16.0	9.4	6.45	72
10a ..	10.0	25	75	0	100	0	2.22	7.2	.80	8.4	3.70	7.3	1.40	15
10b ..	10.0	25	75	50	50	2.5	2.03	8.6	1.72	20	7.30	9.0	3.80	42
5a ...	5.0	25	75	0	100	0	1.28	6.8	.84	9.0	1.78	6.7	1.12	11
5b ...	5.0	25	75	50	50	1.25	1.18	8.4	1.02	10	2.42	7.7	1.98	20
1a ...	1.0	25	75	0	100	0	.40	7.1	.22	2.4	.32	6.4	.25	2.4
1b ...	1.0	25	75	50	50	.25	.36	7.0	.24	2.6	.34	6.4	.22	2.1
5aL....	5.0	75	25	0	100	0	1.02	6.9	.22	2.2	1.50	6.1	.23	2.2
5bL....	5.0	75	25	85	15	.50	.69	8.1	.29	3.1	1.05	7.4	.36	3.5
1aL....	1.0	75	25	0	100	0	.34	7.0	.14	1.5	.36	6.4	.12	1.1
1bL....	1.0	75	25	85	15	.10	.33	7.2	.14	1.4	.34	6.4	.13	1.3

with respect to soil texture, infiltration rate, drainage, quantity of water used, climate, and salt tolerance of crop. Large deviations from the average for one or more of these variables may make it unsafe to use what, under average conditions, would be a good water; or may make it safe to use what, under average conditions, would be a water of doubtful quality. This relationship to average conditions must be kept in mind in connection with the use of any general method for the classification of irrigation waters.

A diagram for classifying irrigation waters was suggested by Wilcox (1948), and this was subsequently modified by Thorne and Thorne (1951) for the classification of the irrigation waters of Utah. Both diagrams have been widely used. In the classification presented below, certain features of both diagrams are used. However, the SAR value rather than the soluble-sodium percentage is taken as the index of sodium status or sodium hazard.

Salinity Hazard

Waters are divided into four classes with respect to conductivity, the dividing points between classes being at 250, 750, and 2,250 micromhos/cm. (See figure 25). These class limits were selected in accordance with the relationship between the electrical conductivity of irrigation waters and the electrical conductivity of saturation extracts of soil as discussed previously in this chapter under the heading, Electrical Conductivity. The frequency distribution of the electrical conductivity of three groups of irrigation waters with respect to these four classes has been determined on the basis of number of water sources and acreage irrigated. These three groups of data were compiled from the following sources:

Group 1. Data from Laboratory files for 1,142 irrigation water sources, both surface and ground water.

Group 2. Data estimated from figure 1, page 10, of Utah Agr. Expt. Sta. Bul. 346; Irrigation Waters of Utah, by Thorne and Thorne (1951).

Group 3. All conveniently available data from projects irrigated with surface waters of known and reasonably constant composition.

The frequency distribution of the first two groups is with respect to the number of sources, while distribution of the third group is with respect to acres irrigated. These data are presented in table 13. The frequency-distribution curves for the first two groups of waters are shown in figure 24.

It is apparent that more than half of the waters considered in table 13 have conductivity values below 750 micromhos/cm., the lowest limit used in the earlier schemes of classification. The establishment of a class limit at 250 micromhos/cm. further divides this large group. Considering the first group of data, 11 percent of the sources had conductivity values below 250 micromhos/cm. and are in the low-salinity class. The waters of the medium-salinity class have conductivities of 251 to 750 micromhos/cm. and comprise 47 percent of the sources. The remaining 42 percent represent irrigation waters of high or very high salinity. Distribution of waters in group 2 is similar to those in group 1.

Sodium Hazard

The establishment of water-quality classes from the standpoint of the sodium hazard is more complicated than for the salinity hazard. The problem can be approached from the point of view of the probable ex-

TABLE 12.—Chemical composition of some river waters used for irrigation in western United States ¹

River	Location	Date sampled	EC×10 ⁶ at 25° C.	Dis- solved solids	Sum of cations	Boron	Milliequivalents per liter								SSP	SAR	Residual Na ₂ CO ₃
							Ca	Mg	Na	K	CO ₃	HCO ₃	SO ₄	Cl			
				P. p. m.	Meq./l.	P. p. m.											Meq./l.
Missouri ²	Williston, N. Dak.....	11/29/45	838	574	9.48	0.1	3.49	2.38	3.48	0.13	0	3.54	5.39	0.34	37	2.0	0
Yellowstone.....	Miles City, Mont.....	7/22/48	548	368	5.71	.11	2.27	1.22	2.11	.11	(³)	2.40	2.96	.15	37	1.6	0
North Platte ²	Wyoming-Nebraska lines.....	10/8/45	828	565	8.99	.1	3.59	1.64	3.61	.15	0	4.46	3.98	.54	40	2.2	0
South Platte.....	Englewood, Colo.....	7/11/44	406	246	4.07	.03	1.84	.87	1.28	.08	.10	1.99	1.21	.69	31	1.1	0
Platte.....	Aurora, Nebr.....	7/21/51	800	571	7.98	.12	2.96	1.67	3.35		.20	2.85	4.56	.76	42	2.2	0
Arkansas.....	La Junta, Colo.....	7/21/44	1,210	981	14.38	.11	7.18	3.49	3.47	.24	(³)	3.95	9.80	.62	24	1.5	0
Do ⁴	Ralston, Okla.....	8/16/44	1,670	967	14.52		4.34	2.14	8.04		0	2.79	4.39	7.28	55	4.5	0
Canadian ⁵	Conchos Dam, N. Mex.....	6/3/43	844	586	9.57		3.64	2.63	3.30		0	2.72	6.33	.51	34	1.9	0
Rio Grande.....	Otowi Bridge, N. Mex.....	6/46	340	227	3.39		1.86	.70	.83		(³)	1.77	1.50	.14	24	.7	0
Do.....	El Paso, Tex.....	6/46	1,160	754	11.54	.14	4.16	1.42	5.96		.05	3.59	5.00	3.10	52	3.6	0
Do.....	Roma, Tex.....	6/46	607	380	5.76	.11	2.49	.86	2.41		0	2.03	1.88	1.88	42	1.9	0
Pecos ²	Carlsbad, N. Mex.....	1945/46	3,210	2,380	38.00		17.27	9.21	11.52		0	3.18	23.11	11.99	30	3.2	0
Gila.....	Florence, Ariz.....	4/10/34	1,720	983	16.85	.26	3.59	1.99	11.27		.20	3.68	3.26	9.95	67	6.7	0
Salt.....	Stewart Mountain Dam, Ariz.....	3/8/34	1,210	664	11.27	.10	2.38	1.20	7.69		.39	2.40	.85	7.65	68	5.7	0
Colorado.....	Yuma, Ariz.....	3/21/43	1,060	740	10.96	.10	4.79	2.11	4.06		(³)	2.64	6.39	2.05	37	2.2	0
Sevier ⁶	Central, Utah.....	6/5/49	580	338	5.47	.11	2.50	1.23	1.57	.17	.10	4.10	1.12	.74	29	1.1	.47
Do ⁶	Delta, Utah.....	6/3/49	2,400	1,574	25.81	.46	3.14	6.90	15.31	.46	.33	4.76	8.44	12.52	59	6.8	0
Weber.....	Ogden, Utah.....	10/7/49	510	308	5.58	.03	3.32	1.44	.73	.09	.42	3.66	.82	.54	13	.5	0
Humboldt ⁷	Rye Patch, Nev.....	8/48	1,173	8658	11.55	.62	1.75	1.89	7.91		0	5.20	2.17	4.46	68	5.9	1.56
Sacramento.....	Tisdale, Calif.....	8/15/47	162	108	1.73	.05	.66	.57	.45	.05	0	1.35	.14	.20	26	.6	.12
Kern.....	Bakersfield, Calif.....	9/28/44	234	152	2.36	.20	1.00	.24	1.06	.06	0	1.51	.49	.40	45	1.3	.27
Columbia.....	Wenatchee, Wash.....	11/25/35	151	878	1.48	.05	.90	.39	.19		0	1.26	.21	.07	13	.2	0
Snake ⁹	Minidoka, Idaho.....	1948/49	410	246	4.54		2.15	1.29	.84	.26	.34	2.59	.91	.74	19	.6	0
Payette ⁹	Black Canyon, Idaho.....	1948/49	100	60	.91		.40	.23	.18	.10	0	.63	.18	.12	20	.3	0
Rogue.....	Medford, Oreg.....	9/13/32	108	72	1.15	.09	.54	.26	.33	.02	0	.85	(³)	.25	29	.5	.05

¹ Except as noted, these analyses were made by the Rubidoux Unit, U. S. Salinity Laboratory, Riverside, California. ² After U. S. Geol. Survey (1950). ³ Trace. ⁴ After U. S. Geol. Survey (1949).
⁵ After U. S. Geol. Survey (1945). ⁶ After Thorne and Thorne (1951). ⁷ After Miller (1950). ⁸ Calculated. ⁹ After Jensen and others (1951).

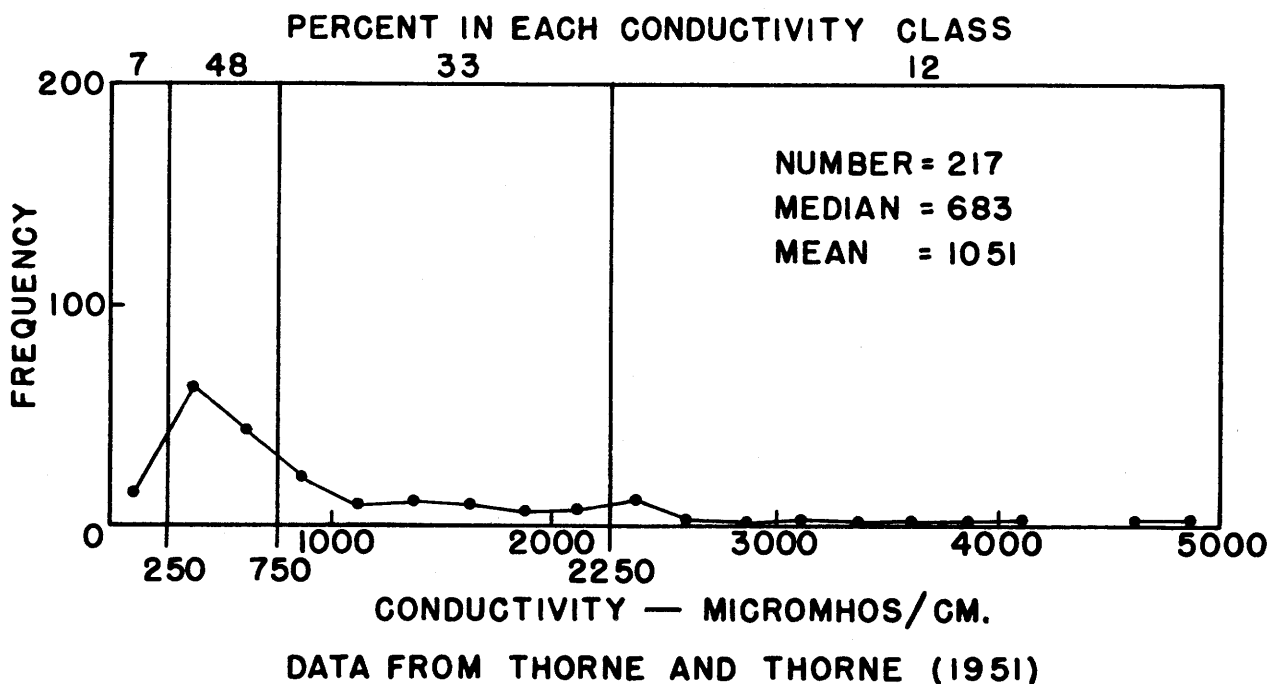
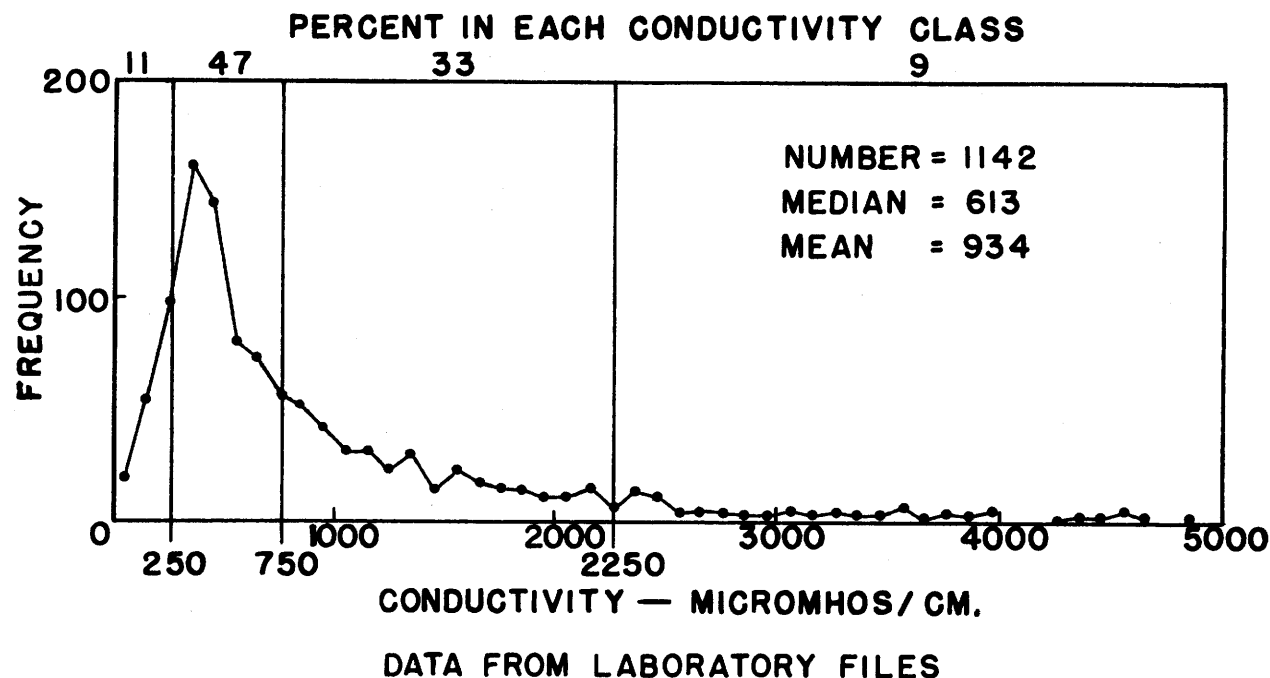


FIGURE 24.—Frequency distribution of two groups of irrigation waters with respect to electrical conductivity.

TABLE 13.—*Distribution of 3 groups of irrigation waters among 4 concentration classes*

Conductivity range (micromhos/cm. at 25° C.)	Group 1		Group 2		Group 3	
	Sam- ples	Per- cent	Sam- ples	Per- cent	Acres	Per- cent
	Num- ber		Num- ber		Thou- sands	
<250.....	124	11	15	7	453	21
251-750.....	541	47	105	48	977	46
751-2,250.....	378	33	71	33	671	32
2,251-5,000.....	99	9	26	12	22	1
Total.....	1,142	100	217	100	2,123	100

tent to which soil will adsorb sodium from the water and the rate at which adsorption will occur as the water is applied. Consider the simple case where a nonalkali soil is leached continuously with a high-sodium irrigation water and an increase in concentration of the salts in the solution is prevented by the absence of plant growth and of surface evaporation. Under these conditions the *ESP* which the soil will attain when it and the water are in equilibrium can be predicted approximately from the *SAR* value of the water; the rate at which the equilibrium condition will be attained will depend on the total cation concentration or electrical conductivity of the water. Thus, for this situation, application of waters having the same sodium-adsorption-ratio and variable electrical conductivities would ultimately result in about the same exchangeable-sodium-percentages, but the amount of water required to bring the soil to this ultimate exchangeable-sodium-percentage would vary inversely with the electrical conductivity. In actual practice, the *SAR* value of the water increases in the soil, owing to the increase in concentration of all salts and the possible precipitation of calcium and magnesium salts as the moisture content is decreased by plant extraction and surface evaporation. This results in a somewhat higher *ESP* than would be predicted directly from the *SAR* value of the water (fig. 23). Although the *SAR* value is the best available index of the equilibrium *ESP* of soil in relation to irrigation water, total cation concentration or conductivity is an additional factor and is taken into account in the following classification of sodium hazard.

Diagram for Classifying Irrigation Waters

The diagram for the classification of irrigation waters is shown in figure 25 and is based on the electrical conductivity in micromhos per centimeter and the sodium-adsorption-ratio.

In earlier diagrams curves representing mass-action equations between soluble and exchangeable cations delimited the several sodium classes. The curves in figure 25 can be constructed by the use of the following empirical equations:

$$\text{Upper curve: } S = 43.75 - 8.87 (\log C);$$

$$\text{Middle curve: } S = 31.31 - 6.66 (\log C);$$

$$\text{Lower curve: } S = 18.87 - 4.44 (\log C);$$

Where *S*=sodium-adsorption-ratio; *C*=electrical conductivity in micromhos per centimeter; log=logarithm to base 10.

These equations plot as straight lines on rectangular coordinate paper when log *C* is used.

The curves are given a negative slope to take into account the dependence of the sodium hazard on the total concentration. Thus, a water with a *SAR* value of 9 and a conductivity less than 168 is classed, so far as sodium hazard is concerned, as an *S1* water. With the same *SAR* value and a conductivity from 168 to 2,250, it becomes an *S2* water; with a conductivity greater than 2,250, the water is rated *S3*. This system by which waters at a constant *SAR* value are given a higher sodium-hazard rating with an increase in total concentrations is arbitrary and tentative, but it seems to be supported by field and laboratory observations.

To use the diagram, the electrical conductivity and the concentrations of sodium and calcium plus magnesium for the irrigation water are required. The determination of conductivity is described in Method 72; sodium in Methods 80a and 80b; and calcium plus magnesium in Method 79. If only the value for calcium plus magnesium is known, sodium can be estimated as follows:

$$\text{Na}^+ = (EC \times 10^6 / 100) - (\text{Ca}^{++} + \text{Mg}^{++})$$

Conversely, if only sodium is known, calcium plus magnesium can be estimated by the equation:

$$(\text{Ca}^{++} + \text{Mg}^{++}) = (EC \times 10^6 / 100) - \text{Na}^+$$

The ionic concentrations are expressed in milliequivalents per liter. The sodium-adsorption-ratio may be calculated from the equation defining the value or estimated from the nomogram of figure 22. Using the *SAR* and the *EC* values as coordinates, locate the corresponding point on the diagram. The position of the point determines the quality classification of the water. This is illustrated by the analysis of the water of the Sevier River at Delta, Utah (table 12), in which calcium plus magnesium equals 10.04 meq./l.; sodium, 15.31 meq./l.; and electrical conductivity, 2,400 micromhos/cm. The *SAR* value from the nomogram (fig. 22) is found to be 6.8. The point on the diagram corresponding to these coordinates (*SAR*=6.8, $EC \times 10^6 = 2,400$) classifies the water as *C4-S2*.

The significance and interpretation of the quality-class ratings on the diagram are summarized below.

Conductivity

LOW-SALINITY WATER (*C1*) can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

MEDIUM-SALINITY WATER (*C2*) can be used if a moderate amount of leaching occurs. Plants with

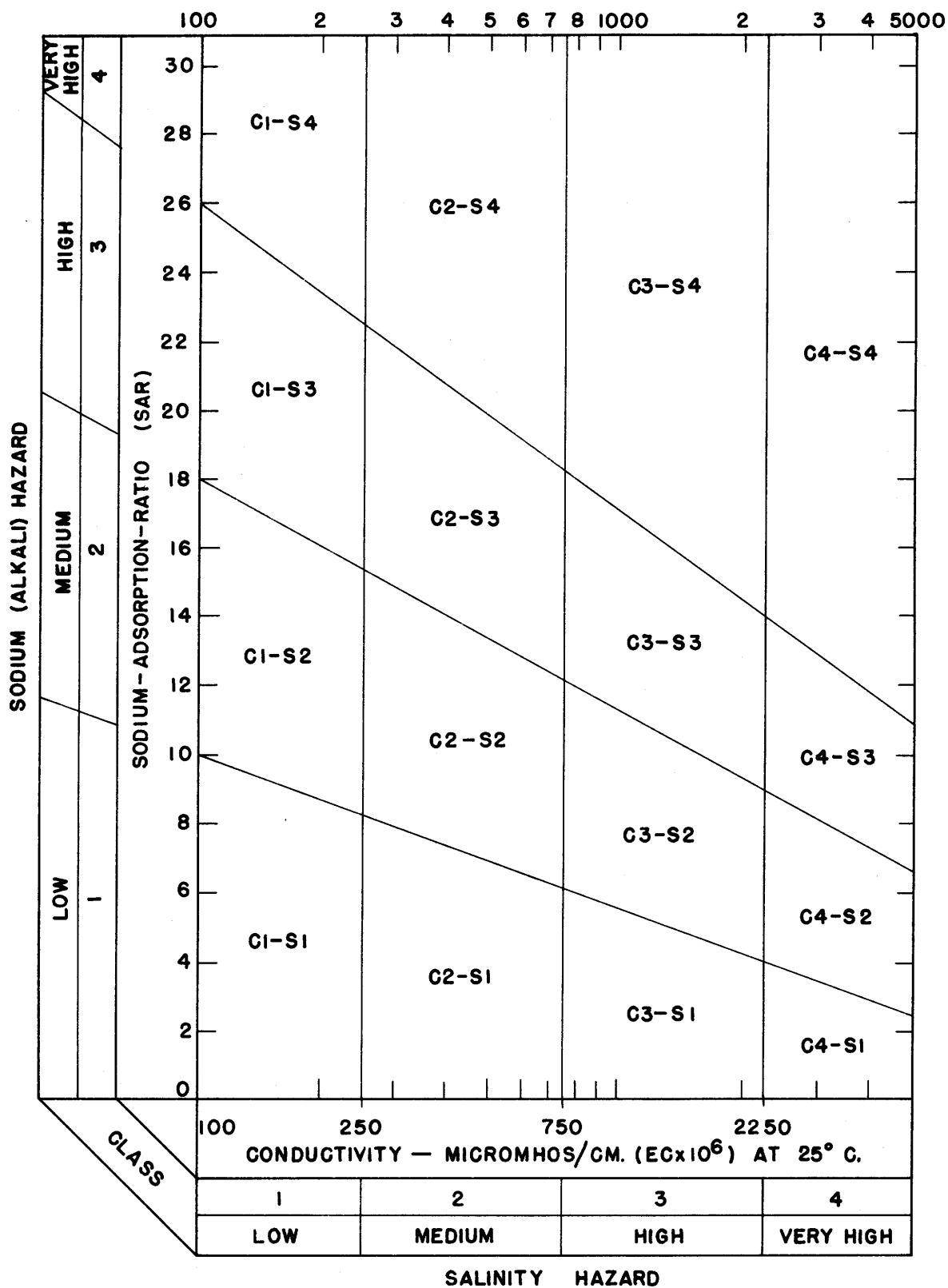


FIGURE 25.—Diagram for the classification of irrigation waters.

moderate salt tolerance can be grown in most cases without special practices for salinity control.

HIGH-SALINITY WATER (C3) cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

VERY HIGH SALINITY WATER (C4) is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected.

Sodium

The classification of irrigation waters with respect to *SAR* is based primarily on the effect of exchangeable sodium on the physical condition of the soil. Sodium-sensitive plants may, however, suffer injury as a result of sodium accumulation in plant tissues when exchangeable sodium values are lower than those effective in causing deterioration of the physical condition of the soil.

LOW-SODIUM WATER (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stone-fruit trees and avocados may accumulate injurious concentrations of sodium.

MEDIUM-SODIUM WATER (S2) will present an appreciable sodium hazard in fine-textured soils having high cation-exchange-capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils with good permeability.

HIGH-SODIUM WATER (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management—good drainage, high leaching, and organic matter additions. Gypsiferous soils may not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium, except that amendments may not be feasible with waters of very high salinity.

VERY HIGH SODIUM WATER (S4) is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.

Sometimes the irrigation water may dissolve sufficient calcium from calcareous soils to decrease the sodium hazard appreciably, and this should be taken into account in the use of C1-S3 and C1-S4 waters. For calcareous soils with high pH values or for non-

calcareous soils, the sodium status of waters in classes C1-S3, C1-S4, and C2-S4 may be improved by the addition of gypsum to the water. Similarly, it may be beneficial to add gypsum to the soil periodically when C2-S3 and C3-S2 waters are used.

Effect of Boron Concentration on Quality

Boron is essential to the normal growth of all plants, but the quantity required is very small. A deficiency of boron produces striking symptoms in many plant species. Boron is very toxic to certain plant species and the concentration that will injure these sensitive plants is often approximately that required for normal growth of very tolerant plants. For instance, lemons show definite and, at times, economically important injury when irrigated with water containing 1 p. p. m. of boron, while alfalfa will make maximum growth with 1 to 2 p. p. m. of boron.

The occurrence of boron in toxic concentrations in certain irrigation waters makes it necessary to consider this element in assessing the water quality. Scofield (1936) proposed the limits shown in table 14.

TABLE 14.—*Permissible limits of boron for several classes of irrigation waters*

Boron class	Sensitive crops	Semitolerant crops	Tolerant crops
	<i>P. p. m.</i>	<i>P. p. m.</i>	<i>P. p. m.</i>
1.....	<0.33	<0.67	<1.00
2.....	0.33 to .67	0.67 to 1.33	1.00 to 2.00
3.....	.67 to 1.00	1.33 to 2.00	2.00 to 3.00
4.....	1.00 to 1.25	2.00 to 2.50	3.00 to 3.75
5.....	>1.25	>2.50	>3.75

The tolerance of crops to boron is discussed in chapter 4 and a boron tolerance list is given in table 9. Boron frequently occurs in toxic concentrations along with the other salts that are present in saline soils. It can be leached from the soil but, if concentrations are high initially, a quantity of boron sufficient to cause trouble may remain after the concentration of other salts is reduced to a safe level. The boron status of saline soils should be determined as a part of a salinity appraisal following Method 17.

Effect of Bicarbonate Ion Concentration on Quality

On the basis of the data given in table 11 and using the "residual sodium carbonate" concept of Eaton (1950), it is concluded that waters with more than 2.5 meq./l. "residual sodium carbonate" are not suitable for irrigation purposes. Waters containing 1.25 to 2.5 meq./l. are marginal, and those containing less than 1.25 meq./l. "residual sodium carbonate" are probably safe. It is believed that good management prac-

tices and proper use of amendments might make it possible to use successfully some of the marginal waters for irrigation. These conclusions are based on limited data and are, therefore, tentative.

In appraising the quality of an irrigation water, first consideration should be given to salinity and alkali

hazards by reference to figure 25. Then consideration should be given to the independent characteristics, boron or other toxic elements, and bicarbonate, any one of which may change the quality rating. Recommendations as to the use of a water of a given quality must take into account such factors as drainage and management practices.